W/Z Separation

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Muon Collider Physics Workshop

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Fermilab

Overview

- Physics motivations
- 4^{th} Detector baseline for lepton colliders
- 4^{th} Detector performance
- Jet-finder strategy
- Results from studies at ILC, CLIC and MC

Preliminary

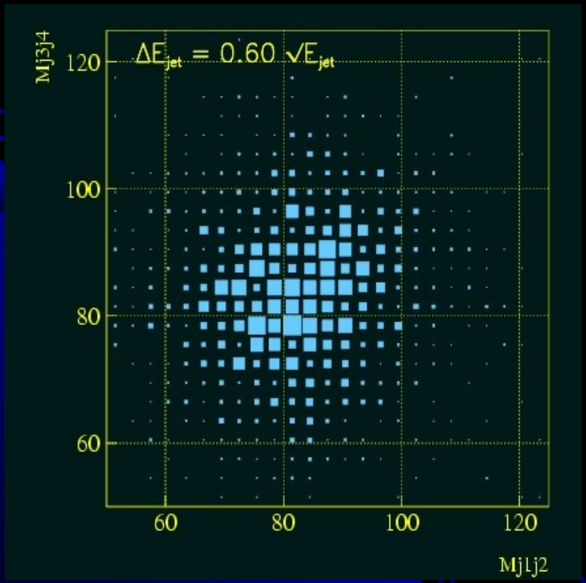
Why W/Z separation is important?

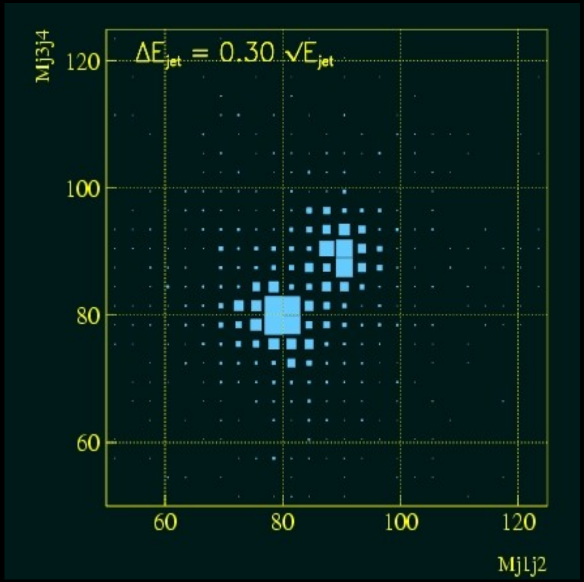
- Physics program of next generation of colliders after LHC not fully defined until results from LHC
- Nevertheless still want to separate W/Z in their hadronic decays
- Separation of W and Z bosons crucial in a lepton collider experiment for several reasons:
  - To disentangle competing channels (e.g. Charginos from Neutralinos)
  - To test Standard Model coupling to gauge bosons and check for deviations

W/Z Separation at ILC

- It has been considered a fundamental issue from day 1 by ILC
- It set the goal of 30%/sqrt(E) on calorimetry

Z/W → jj can be reconstructed and separated





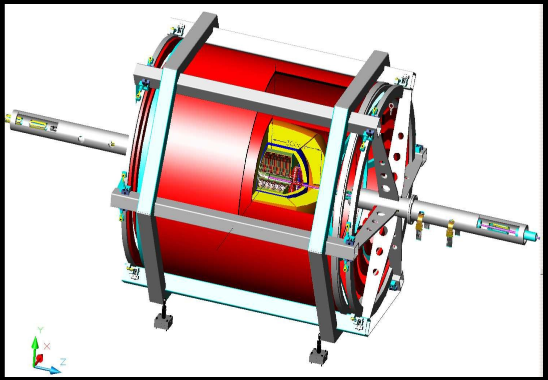
$\sigma_E = 60\%/\sqrt{E(GeV)}$

$\sigma_E = 30\%/\sqrt{E(GeV)}$

W/Z Separation at Multi TeV Colliders

- Even more difficult because:
  1. jet energy resolution degrades as sqrt(E)
  2. Beam background deposits GeV of energy over the area occupied by a jet
- New studies are necessary to understand how a detector should be designed

The 4th Detector for Physics Studies



At ILC

1. Vertex Detector 20-micron pixels (VXD)
2. Drift Chamber He based (DCH)
3. Multiple-readout calorimeter (ECAL &HCAL)
4. Dual-solenoid with Muon Spectrometer (MUD)

See today C. Gatto's talk

At CLIC

Modification of 4th Concept Detector for 3 TeV Physiscs

1. Vertex Detector 20-micron pixels (VXD)
2. Silicon Tracker 50-micron pixels (SIPT)
3. Forward Tracker Disks (preliminary version) (FTD)
4. Double-readout calorimeter (ECAL & HCAL)
5. Dual-solenoid with Muon Spectrometer (MUD)

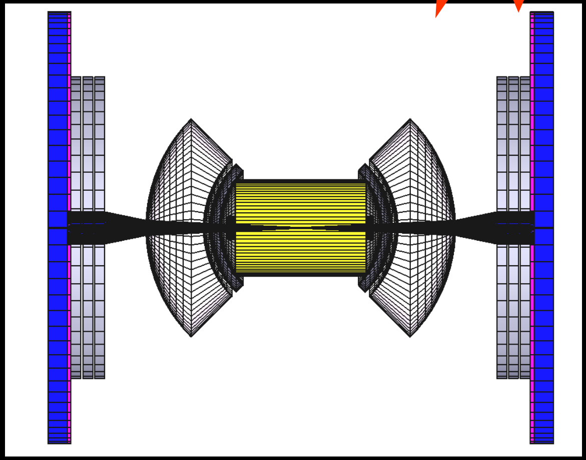
Replace the Drift Chamber

The 4th Detector for Physics Studies

At MC (same as CLIC but shielding)

1. **Inner Tungsten nose + Borate Polyethylen and Tungsten walls**
2. Vertex Detector 20-micron pixels (VXD)
3. Silicon Tracker 50-micron pixels (SIPT)
4. Forward Tracker Disks (preliminary version) (FTD)
5. Double-readout calorimeter (ECAL & HCAL)

• Dual-solenoid with Muon Spectrometer (MUD)



Shielding has been added to cope with beam background

(according to MDI group)

Two main drawbacks:

•Limit useful detection angles to about 30°

•Cannot prevent background electrons from entering the detector

As we will see next

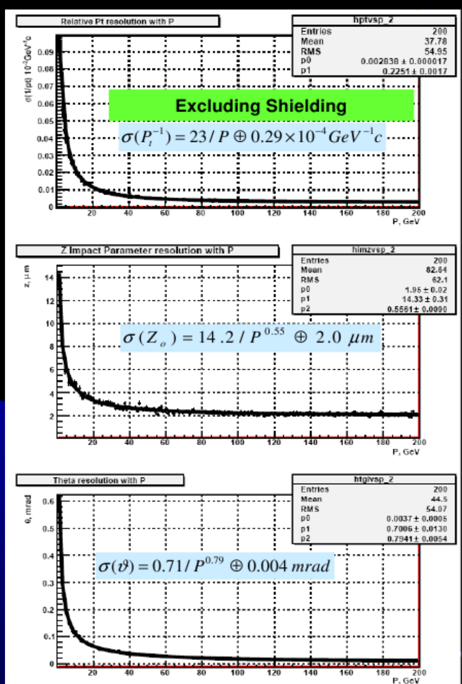
Studies ongoing

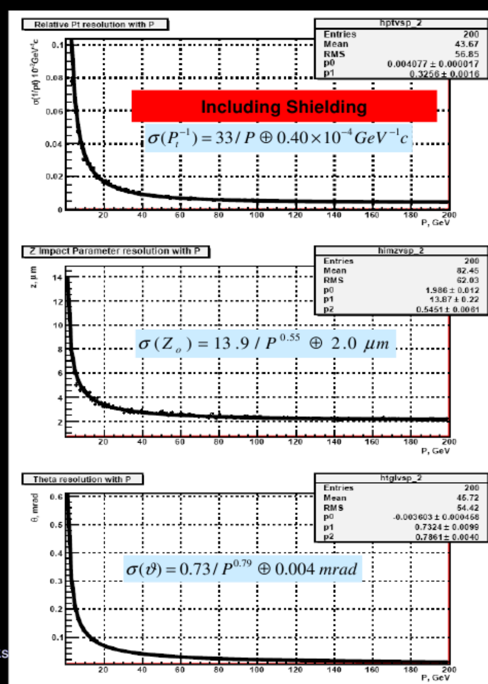
4^{th} Detector Performance

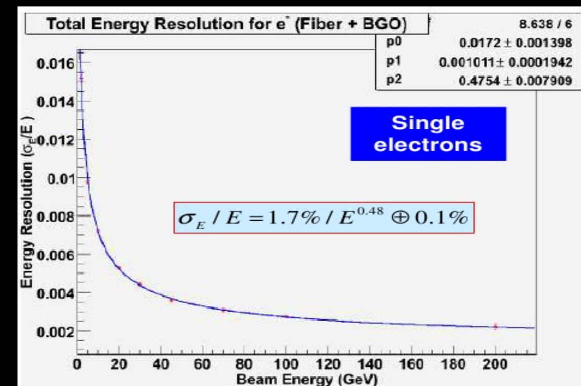
Calorimeter Resolution (without shielding)

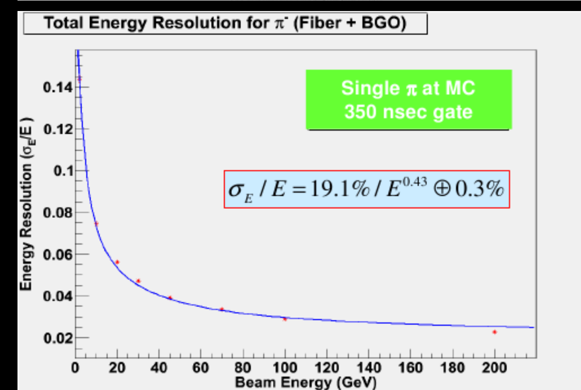
Studies ongoing

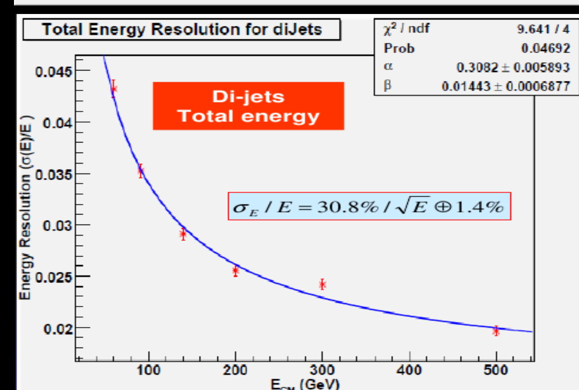
Tracking resolution vs P (single muons)





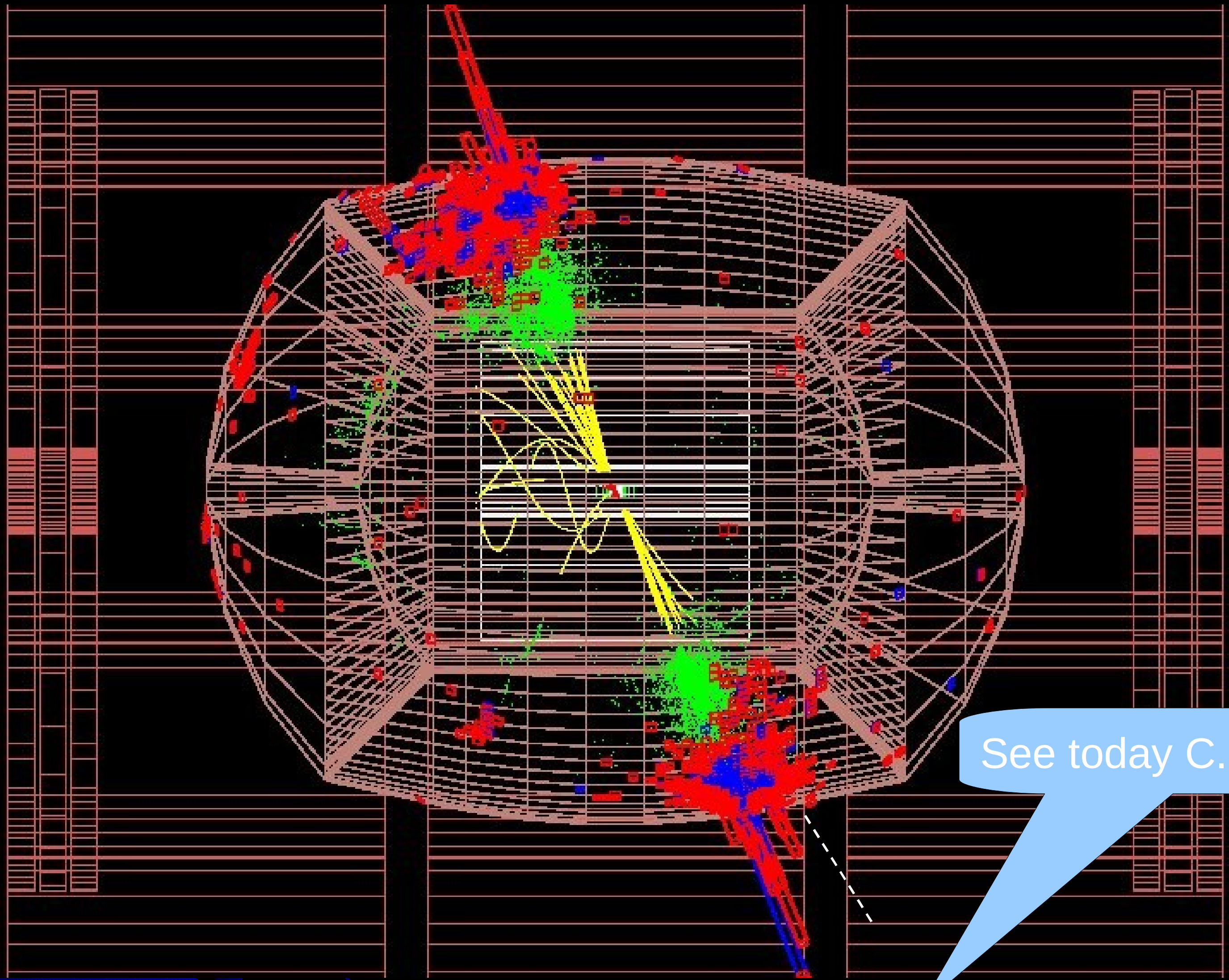






See today C. Gatto's talk
and
tomorrow V. Di Benedetto's talk

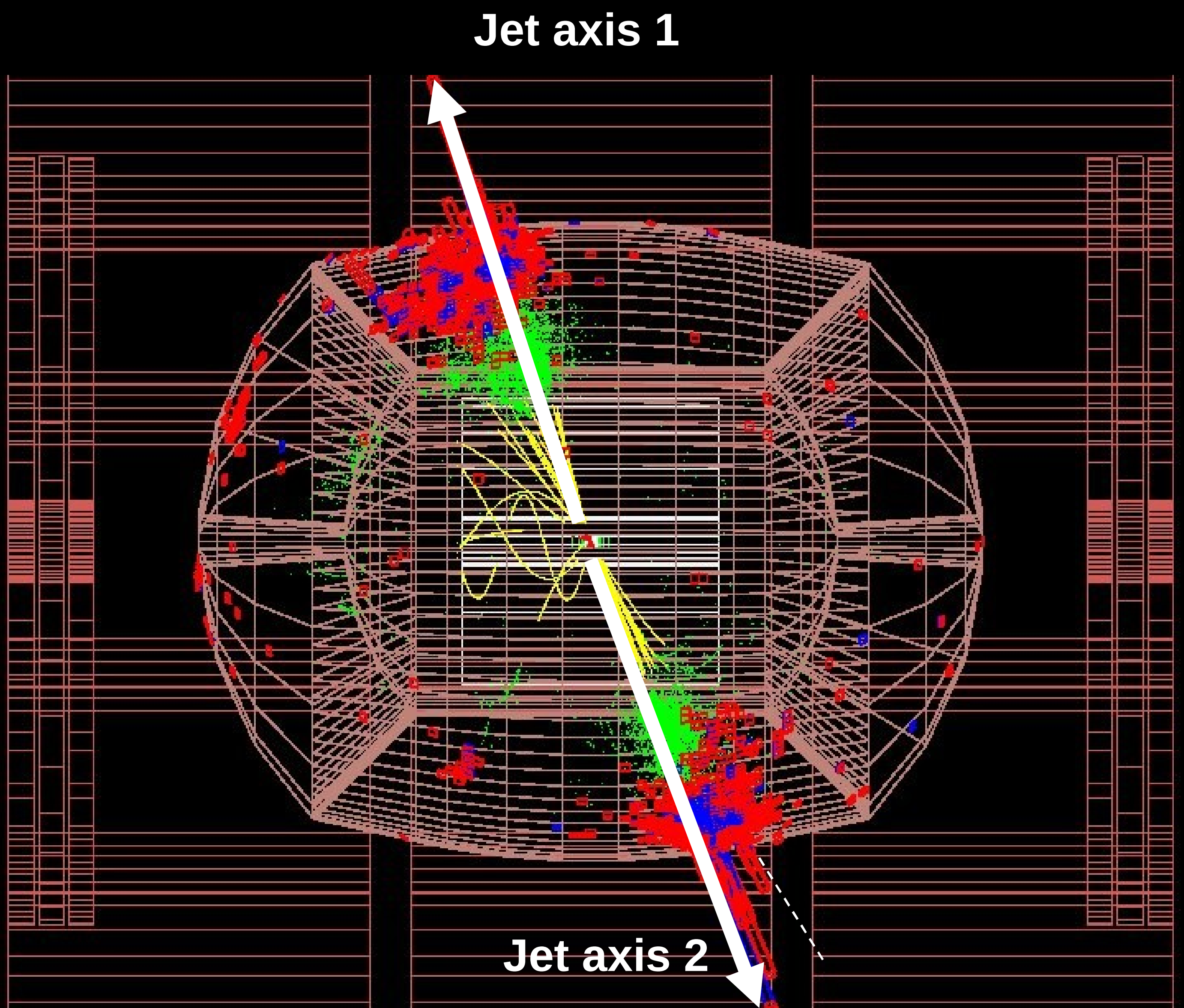
Not Only a Detector, but also a Jet Finder Algorithm



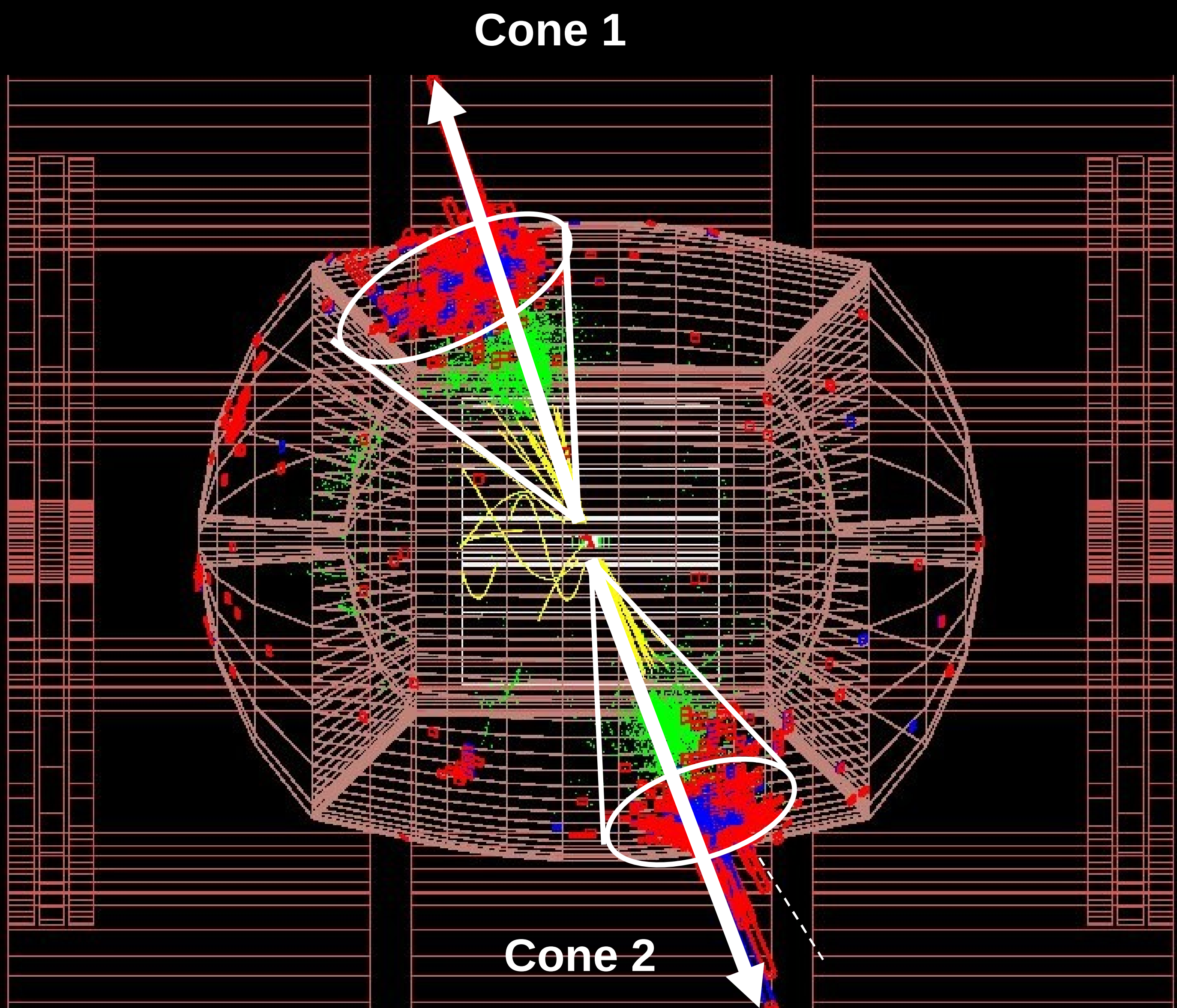
See today C. Gatto's talk

500 GeV Di-Jet event display in ILCroot framework

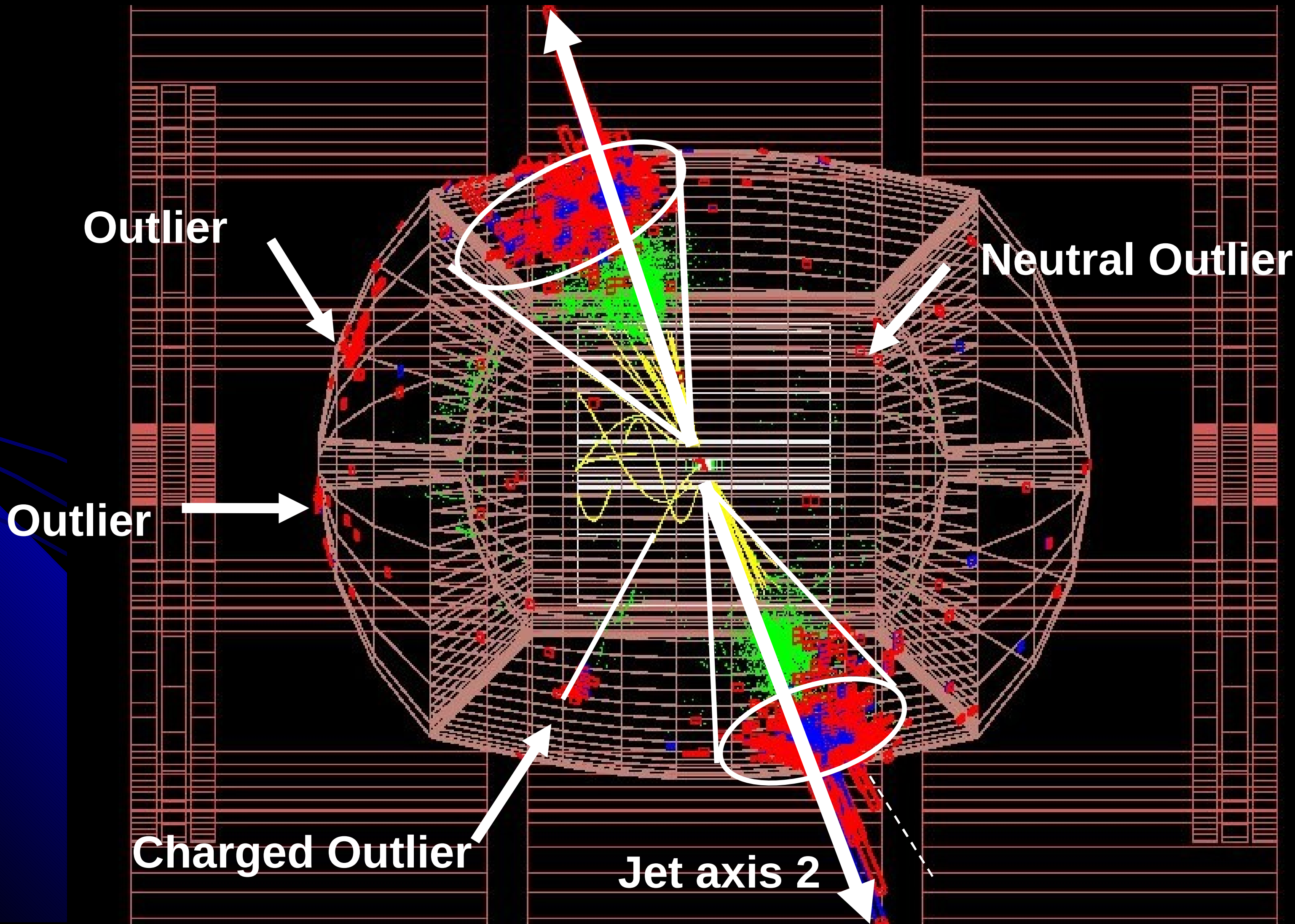
Jet Reconstruction Strategy (1)



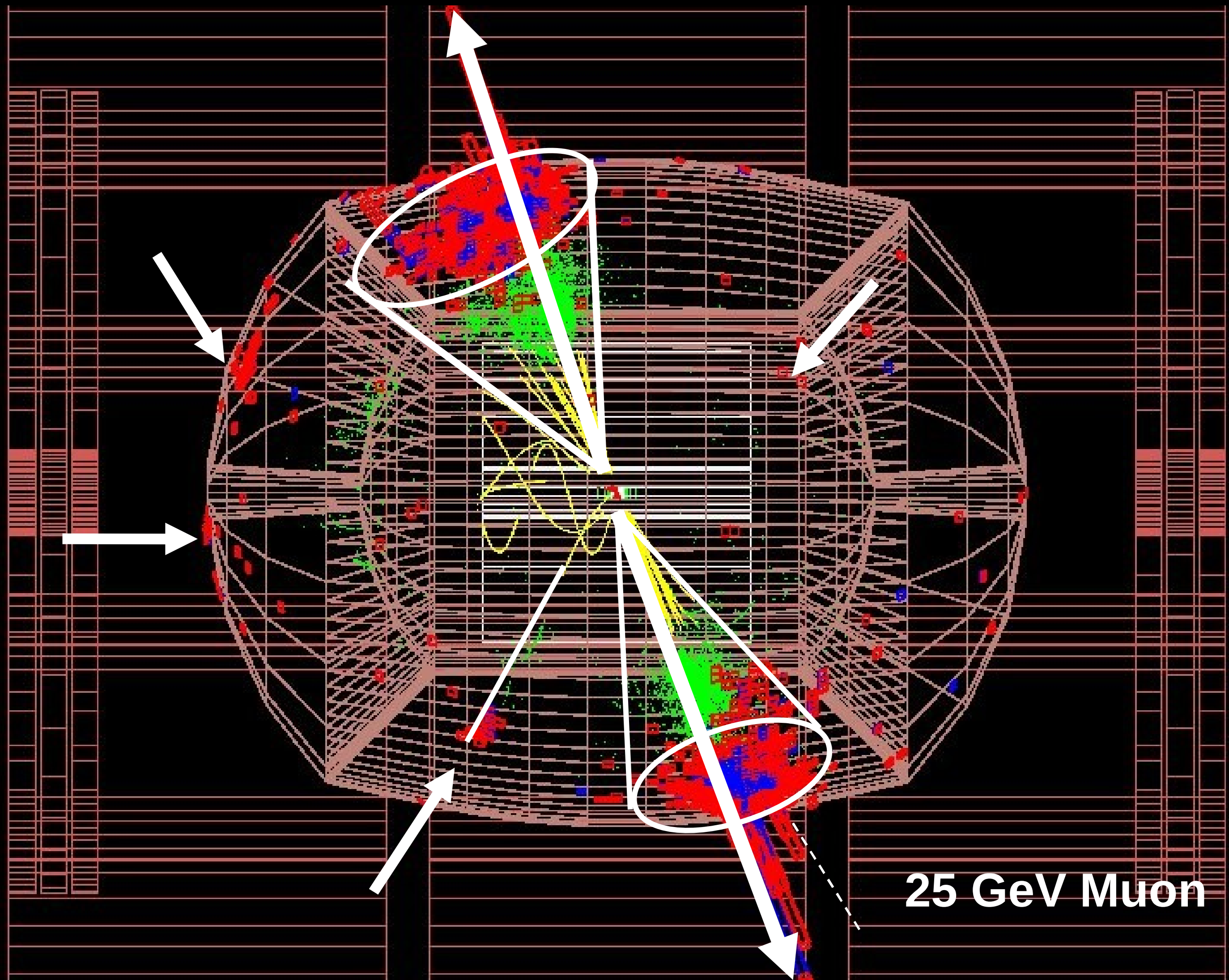
Jet Reconstruction Strategy (2)



Jet Reconstruction Strategy (3)



Jet Reconstruction Strategy (4)



Analysis Performed by the 4th Concept Collaboration for $e^+ e^-$ collider (ILC & CLIC)

$$e^+ e^- \rightarrow W^+ W^- \nu \bar{\nu}$$

$$e^+ e^- \rightarrow Z^0 Z^0 \nu \bar{\nu}$$

WW scattering

$$e^+ e^- \rightarrow \tilde{\chi}_1{}^+ \tilde{\chi}_1{}^- \rightarrow \tilde{\chi}_1{}^0 \tilde{\chi}_1{}^0 W^+ W^-$$

$$e^+ e^- \rightarrow \tilde{\chi}_2{}^0 \tilde{\chi}_2{}^0 \rightarrow \tilde{\chi}_1{}^0 \tilde{\chi}_1{}^0 Z^0 Z^0$$

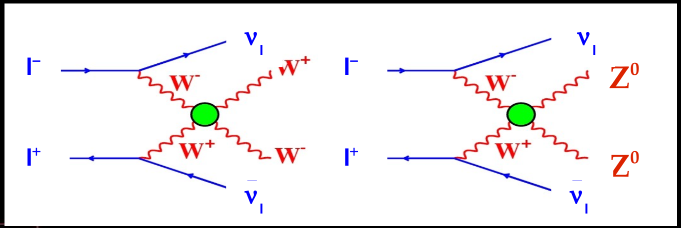
Chargino/Neutralino production

Signature (hadronic W/Z decays) : 4 jets + missing energy

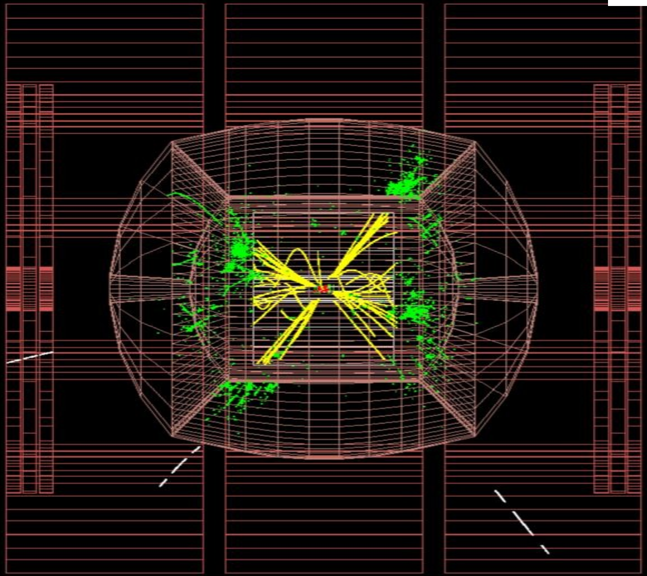
WW/ZZ separation : good calorimeter and tracking performance
(established good jet finder algorithm and best jet association)

WW Scattering

At ILC



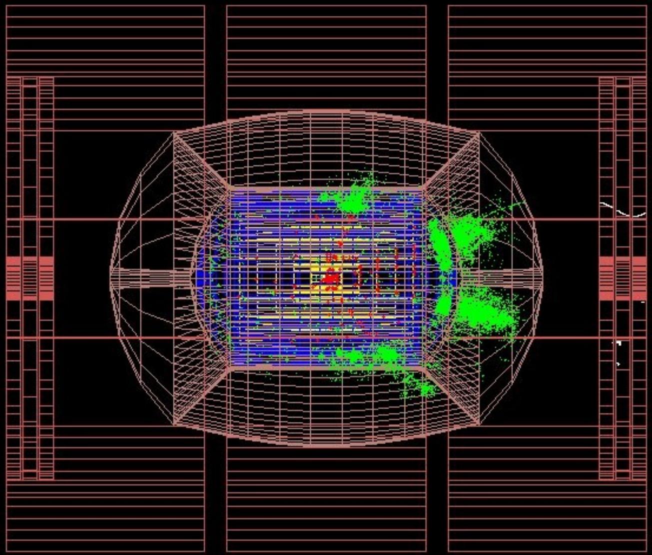
At CLIC



Multi-jets

physics

environment



	E_{CM} (GeV)	Generator	MC	Simulation
ILC	500	Pythia 6.4.16	Fluka	Full (ILCroot)
CLIC	3000	Pythia 6.4.16	Fluka	Full (ILCroot)
MC	1500	Pythia 6.4.16	Fluka	Full (ILCroot)

Preliminary

WW Scattering (ILC)

Only signal present in the analysis :

Channel	Number of events	Generator
$e^+ e^- \to W^+ W^- \nu_e \bar{\nu}_e \to q \bar{q} q \bar{q} \nu_e \bar{\nu}_e$	~2000	Pythia 6.4.16
$e^+ e^- \to Z^0 Z^0 \nu_e \bar{\nu}_e \to q \bar{q} q \bar{q} \nu_e \bar{\nu}_e$	~2000	Pythia 6.4.16

Event selection :

- Events forced into 4jets

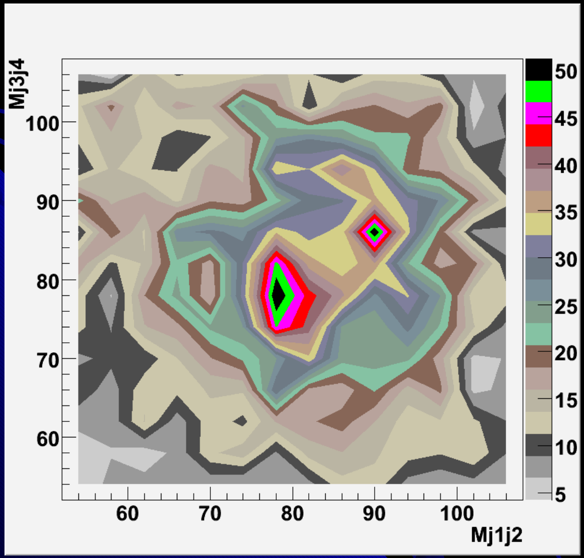
4-jets finding efficiency: 95%

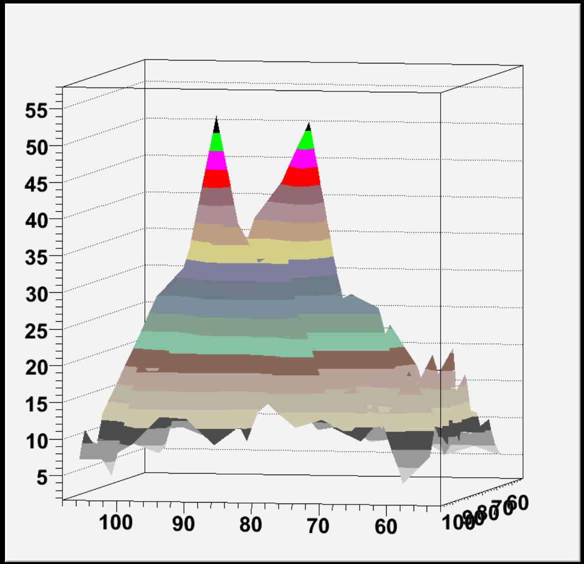
Jet pairing :

All pairs

Presented at LCWS08

All combinations plotted (3 entries/event)





Clear separation between the W and Z peaks obtained with full reconstructed events

WW Scattering (CLIC)

Only signal present in the analysis :

Channel	Number of events	Generator
$e^+ e^- \to W^+ W^- \nu_e \bar{\nu}_e \to q \bar{q} q \bar{q} \nu_e \bar{\nu}_e$	~5000	Pythia 6.4.16
$e^+ e^- \to Z^0 Z^0 \nu_e \bar{\nu}_e \to q \bar{q} q \bar{q} \nu_e \bar{\nu}_e$	~5000	Pythia 6.4.16

Event selection :

- Events forced into 4jets

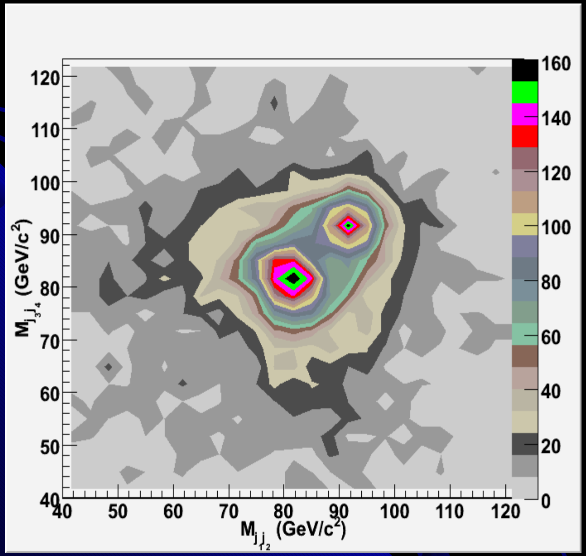
4-jets finding efficiency: 98%

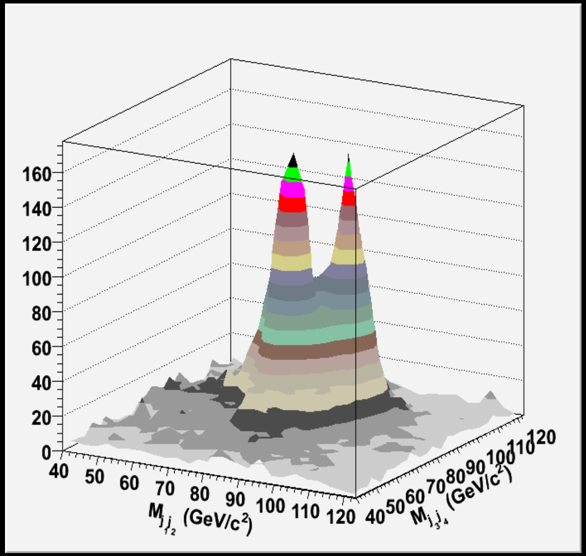
Jet pairing :

All pairs

Presented at CLIC09

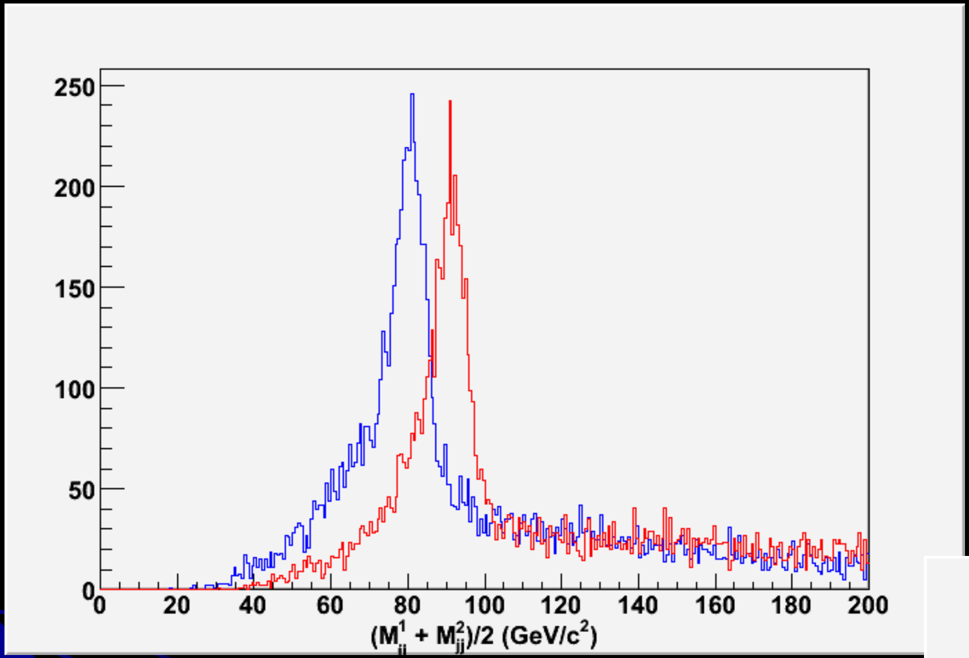
All combinations plotted (3 entries/event)





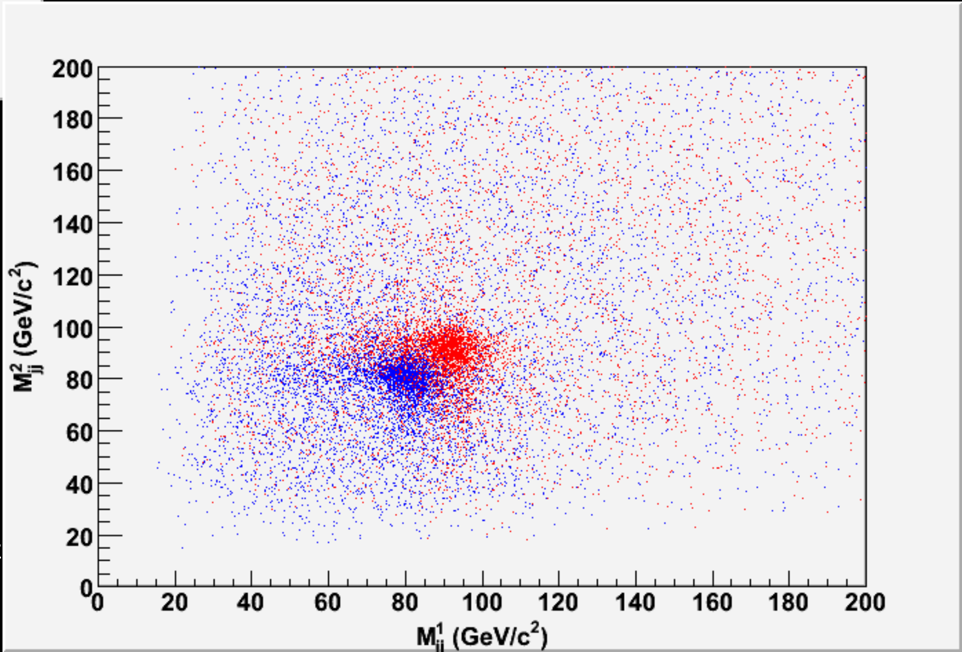
Clear separation between the W and Z peaks obtained with full reconstructed events

WW Scattering (CLIC)



Presented at CLIC09

All combinations plotted
(3 entries/event)



WW Scattering (MC)

Only signal present in the analysis :

Channel	Number of events	Generator
$\mu^+\mu^- \to W^+W^-\nu_\mu\bar{\nu}_\mu \to q\bar{q}q\bar{q}\nu_\mu\bar{\nu}_\mu$	~5000	Pythia 6.4.16
$\mu^+\mu^- \to Z^0Z^0\nu_\mu\bar{\nu}_\mu \to q\bar{q}q\bar{q}\nu_\mu\bar{\nu}_\mu$	~5000	Pythia 6.4.16

Event selection :

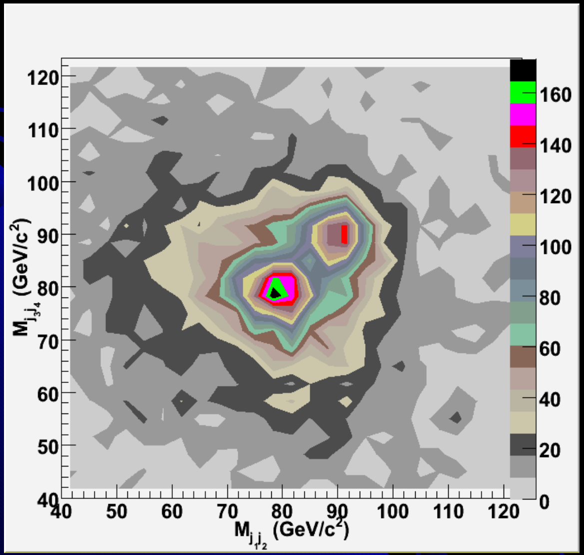
- Events forced into 4jets

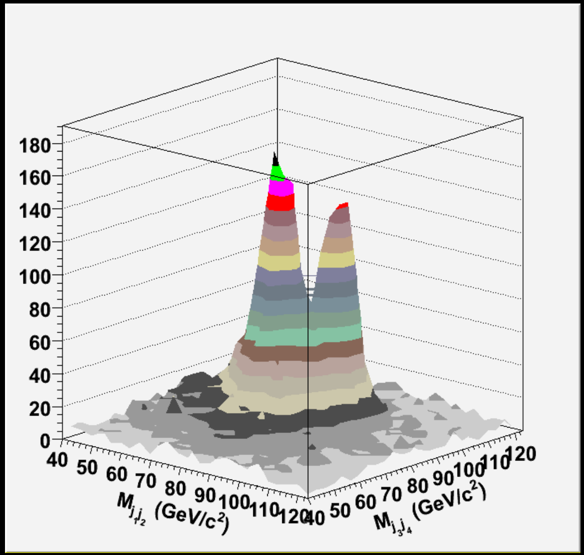
4-jets finding efficiency: 98%

Jet pairing :

All pairs

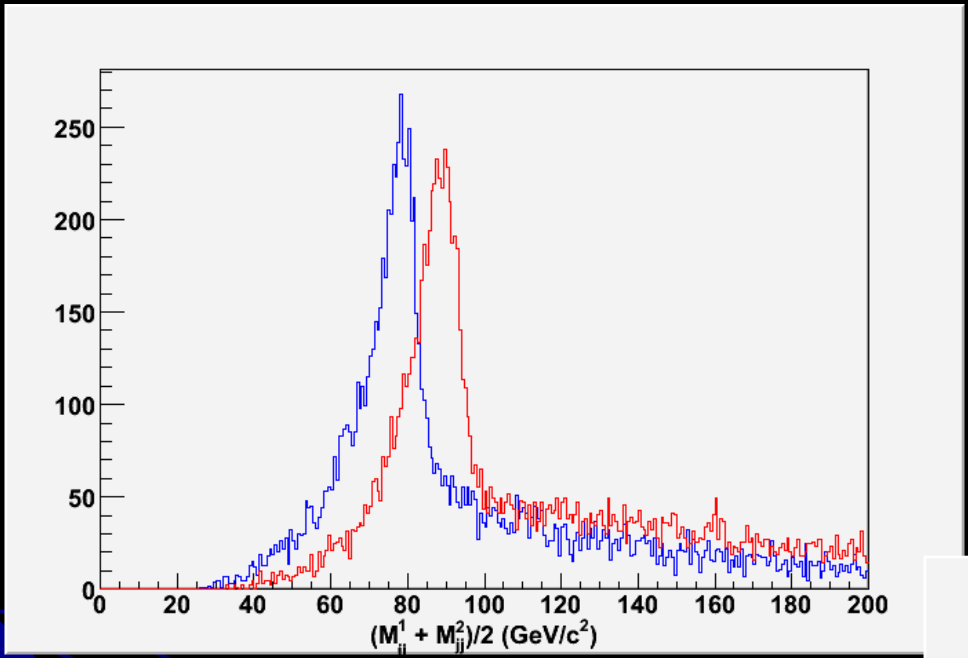
All combinations plotted (3 entries/event)





Clear separation between the W and Z peaks obtained with full reconstructed events

WW Scattering (MC)



- Expected better results

  3 TeV (Clic) → 1.5 TeV (MC)
- Effects of the shielding on the signal:

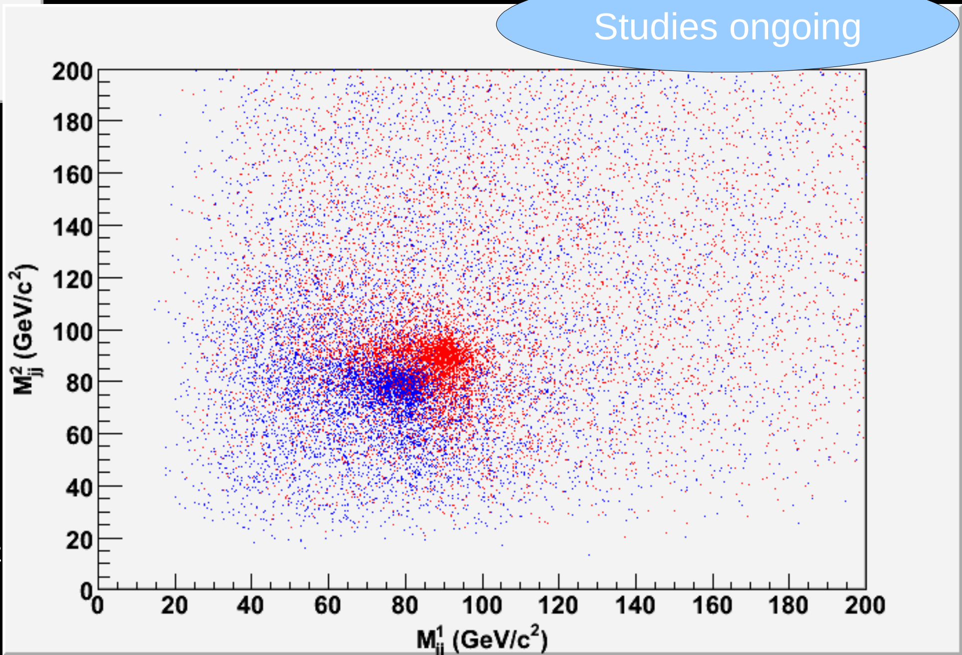
  - mean values at lower masses

  - width distributions larger
- Expected worse results with beam background

Studies ongoing

All combinations plotted
(3 entries/event)

Preliminary



Chargino/Neutralino (ILC)

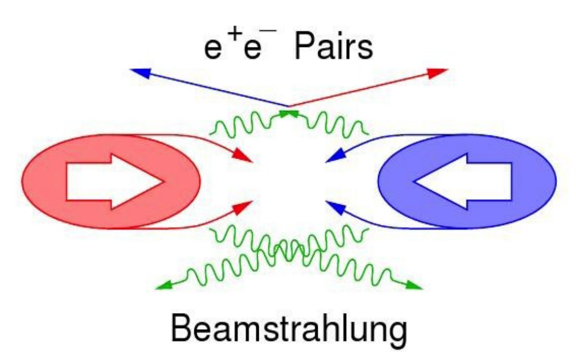
$$e^+e^- \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \to W\tilde{\chi}_1^0 \; W\tilde{\chi}_1^0 \to q\bar{q}'\,\tilde{\chi}_1^0 \; q\bar{q}'\,\tilde{\chi}_1^0$$

$$e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0 \; Z\tilde{\chi}_1^0 \to q\bar{q}\,\tilde{\chi}_1^0 \; q\bar{q}\,\tilde{\chi}_1^0$$

E_{CM} (GeV)	Generator	L (fb^{-1})	MC	Simulationn
500	WHIZARD	250	Fluka	Full (ILCroot)

SUSY background included (all kinematically accessible SUSY processes in the choosen scenario “Point 5”)

All 2f $\rightarrow$ 2f, 4f, 6f and some 8 fermions processes in the e^+e^-, $e\gamma$, $\gamma\gamma$ included and provided to all Concepts by SLAC (WHIZARD/PYTHIA)



Chargino/Neutralino (ILC)

Event reconstruction :

Full (ILCroot framework)

List charged traks from trackers

List of HCAL towers and ECAL cells with E >10 MeV

after calorimeters calibration

Jet reconstruction :

Durham algorithm

Jet pairing :

min $|m_1 - m_2|$

To further reduce background:

$|m_1 - m_2| < 5$ GeV/c^2

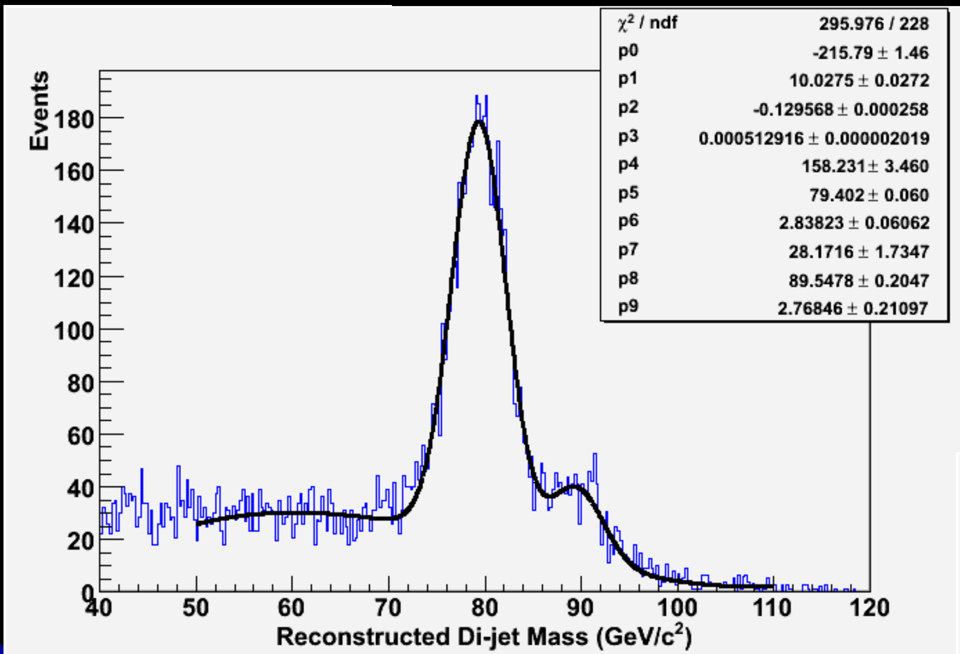
WW/ZZ selection :

Fit on dijet-mass invariant distribution

Event selection :

- Events forced into 4jets (Durham)
- $E_{jet} \geq 5$ GeV
- $|\cos \theta_{jet}| < 0.99$
- $N_{total\ lcharged\ tracks\ \ in\ jet} \geq 2$
- $N_{total\ charged\ tracks} \geq 20$
- $Y_{cut} > 0.001$
- 100 GeV < E_{vis} < 250 GeV
- $|\cos \theta_{miss\ P}| < 0.8$
- $M_{miss} > 220$ GeV/c^2
- No lepton with $E_{lepton} > 25$ GeV

Chargino/Neutralino (ILC)



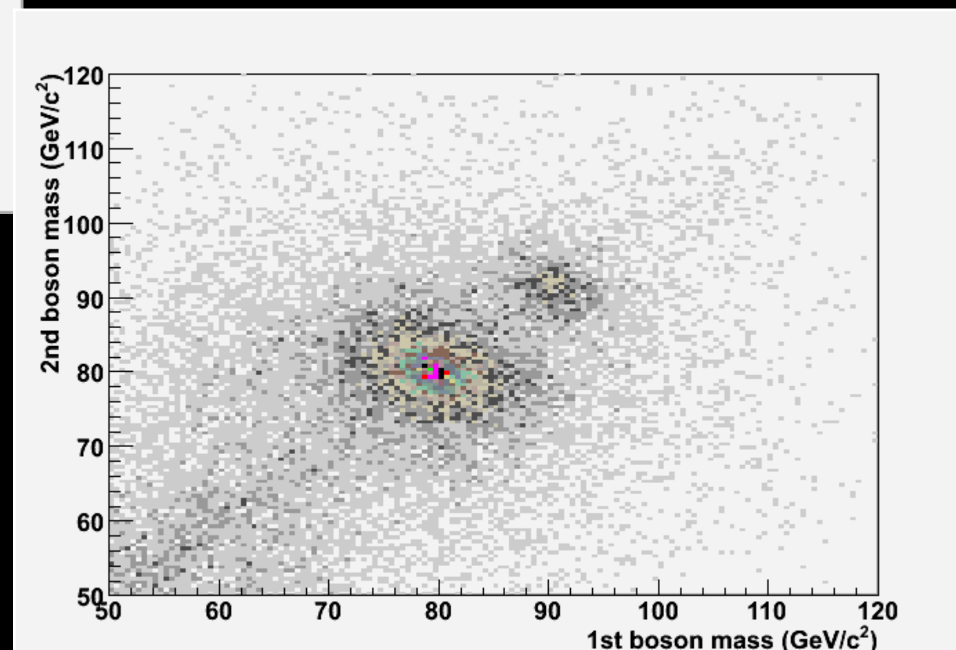
Fitted distribution (double gaussian plus 3rd order polynomial)

$M_W = 79.40 \pm 0.06$ GeV/c^2
$\sigma_W = 2.84 \pm 0.06$ GeV/c^2

$M_Z = 89.55 \pm 0.20$ GeV/c^2
$\sigma_Z = 2.77 \pm 0.21$ GeV/c^2

Reconstructed masses after selection cuts and jet pairing

$\varepsilon_{chargino} = 30.3\%$ $\varepsilon_{neutralino} = 28.6\%$



Clear separation between the W and Z peaks obtained with full reconstructed events (signal + background)

Conclusions

- Separation of W and Z bosons in the hadronic decay physics is crucial in next lepton collider experiments
- 4th Concept Detector achieves excellent W/Z separation for ILC experiment
- W and Z separation preserved at 3 TeV (CLIC)
- For MC preliminary studies indicate that overall detector performance is quite optimal
- Simulation with full backgrounds next step
- Accurate studies needed to understand how shielding can affects physics

Backup slides

Muon Collider

Detector design and requirements motivated by physics and driven by machine environment

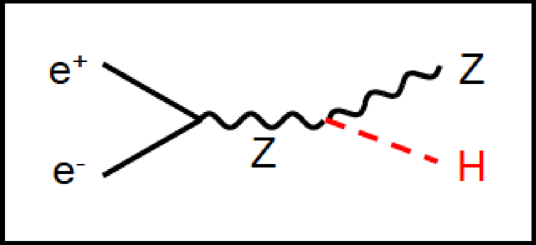
One of the most serious issues in the design of a Muon Collider (MC) is the background arising from beam muon decays (major source of background at MC)

Large backgrounds in the detector can spoil the high physics potential of a MC

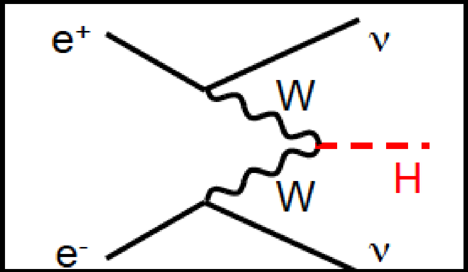
Requirements for ILC Detectors

- Good jet energy resolution to separate W and Z
- Efficient jet-flavor identification capability
- Excellent charged-particle momentum resolution
- Hermetic coverage to veto 2-photon background

S-channel



T-channel



Cross section ∝ 1/S

decreases with S

Particles → barrel region

Cross section ∝ log S

increases with S

Particles → forward region

Jet Reconstruction algorithm

- Associate “close” to each other “particles”
  ⟹ Clustering

- Calculate jet 4momentum from “particles” 4momenta
  ⟹ Recombination

⇓

Not only energy but also direction

“particles” ⟹ **charged tracks or calorimeter clusters or calorimeter towers**

“close” ⟹ **distance**

different algorithms – different distance – different recombination scheme

Durham Algorithm

- Initial set of particles (reconstructed tracks, calorimeter cells, etc.)
- Calculate Yij value of every pair of particles according to:

$$Y_{ij} = \frac{2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{E_{CM}^2}$$

- Pair with smallest Y_{ij} merged into one, provided $Y_{ij} < Y_{cut}$
- New particle with four-momenta: $p_k = p_i + p_j$
- Joining procedure repeated until all pairs of particles have separation above Y_{cut}
- Final set of particles called jets

Jet Reconstruction strategy

Assume the jet made of 2 non-overlapping regions

Core: region of the calorimeter with overlapping showers

Outliers: hit towers separated from the core

Measure the Jet axis

using information from the tracker detectors

Measure the Core energy

using information from the calorimeter

Reconstruct Outliers individually

using tracking and/or calorimetry

depending on the charge of the particle

Add Muons escaping from calorimeter

using muon spetrometer